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Promoting interdisciplinarity in engineering teaching

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Abstract

With funding from the UK's Royal Academy of Engineering, the University of Edinburgh has developed a series of truly interdisciplinary design courses aimed at improving penultimate-year students' ability to operate across disciplines and improve their preparation for industry. Led by a Visiting Industrial Professor, the course on hydropower design requires students to provide a full feasibility study of a small scheme in western Scotland tackling issues from hydrology through to grid connection. The course has had several very successful outcomes which include: appreciation of other engineering disciplines; experience of teams where different skills and expertise are available; demonstration of the links between engineering design and economic viability; introduction to non-technical areas essential to the UK Standard for Professional Engineering Competence; and enhancing interest in the hydropower sector in technological and career terms. The key message from this project is the need to ensure balance across tasks, within groups and staff support across disciplines.

Keywords

Interdisciplinary; engineering; design

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1 Introduction

The supply of appropriately qualified and skilled engineering graduates is essential for the modern economy. However, a significant minority of United Kingdom (UK) engineering firms in the report that engineering graduate shortages and skills deficiencies are costing them money through delays in product development and additional recruitment costs (Spinks *et al.* 2006). Specific skill gaps were found in problem solving, application of theory to real problems and breadth of knowledge. With less than half of the engineering cohort choosing to enter the engineering profession after graduation there is need to develop graduates with the necessary skill sets.

The skills expected to be developed in UK undergraduate degree courses are specified by the Engineering Council UK, the body responsible for 'setting and maintain realistic and internationally recognised standards of professional competence and ethics for engineers, technologists and technicians' (Engineering Council UK 2006). The UK Standard for Professional Engineering Competence (typically referred to as UK-SPEC) outlines a range of learning outcomes which relate to: underpinning science and mathematics; engineering analysis; design; economic, social, and environmental context; and engineering practice (Engineering Council UK 2004). Many of the requirements in UK-SPEC are a challenge to teach directly in universities as they relate directly to practical experience.

The challenges are compounded by the changing role of graduate engineers. The traditional model of engineering is based around single disciplines and the expectation that graduates work within their specialism to with specifications issued by third parties (Royal Academy of Engineering 2006). As a result, students identify strongly with their own engineering discipline and are usually very ignorant (and often dismissive!) of other disciplines. Large employers currently expect graduates to join multi-functional teams developing complex systems within which graduates of traditional single-discipline degree courses may feel ill-prepared. Amongst smaller companies, there is a need for graduates who can cross disciplines, handling and integrating technologies and techniques associated with them (Royal Academy of Engineering 2006).

Approaches to preparing engineering graduates for industrial careers feature frequently in industrial and academic literature (e.g., Lee and Messerschmitt 1998, Todd *et al.* 1993, Todd and Yamada 1996). The broad approach in the United States is to offer so-called ‘Capstone’ courses that draw together knowledge gained in earlier years and apply it in open-ended ‘real world’ projects (Todd *et al.* 1995, Dutson *et al.* 1997)). In the UK, the Royal Academy of Engineering (2006) suggests that undergraduate syllabus’ can better prepare graduates by promoting the importance of systems thinking and a ‘whole product’ holistic approach. With this in mind the ‘Visiting Professors’ scheme was instigated which aims both to foster industry–academia links and to help universities teach engineering design to undergraduates in a way that relates to real professional practice. It does this by financing the involvement of industrialists – the ‘Visiting Professors’ – in the design, delivery and assessment of University courses. To date, three programmes have been set up in: Principles of Engineering Design (see Skates (2003) for an overview of how one UK University participated), Engineering Design for Sustainable Development and Integrated System Design. It is through the Integrated System Design strand that the University of Edinburgh has implemented three interdisciplinary design courses including one on hydropower.

2 Interdisciplinary Design Projects

Five UK universities, including the University of Edinburgh, took part in the pilot scheme of the Integrated System Design programme (Royal Academy of Engineering 2006). Following open competition a further 11 universities will be part of the scheme by the end of 2006. Each university was able to interpret the brief in a different way. Some of these have included using the Visiting Professor to facilitate encouragement of systems integration principles and interdisciplinary activities, to extend existing teaching of systems engineering or provide lectures in appropriate modules on fundamental concepts in the early years of the degree. Rather than implement a formal ‘systems engineering’ course, Edinburgh viewed that the best way of developing integrated system design skills was to involve them in designing realistic interdisciplinary projects. This built on many years of running single-discipline group design projects within undergraduate Bachelors and Masters programmes.

The School of Engineering and Electronics is a multi-disciplinary unit so it was feasible to bring together students from all disciplines. In some UK universities students undertake almost entirely common non-honours (first two) years before pursuing discipline specific material. At Edinburgh students take common starter courses before selecting a variant of one the four main engineering disciplines (Chemical, Civil, Mechanical and Electrical) at the start of the second year. A modest amount of interchange is possible as efforts are made to share courses between disciplines. Academic staff within the School are organised in two ways with research conducted thematically (e.g., Materials and Processes, Energy Systems) and teaching discipline-based. This allows areas like Energy Systems in which interdisciplinary research is critical to operate and expand.

With each honours year being of the order of 200 students it was decided to restrict the courses to those on the more advanced Masters of Engineering (MEng) track, a total in excess of 120 students. To manage numbers and to cater for students' preferences and the relative popularity of disciplines, three separate projects were developed. The scope and subject matter aimed to offer opportunities for truly significant interdisciplinarity involving as many of the four main disciplines as possible. This differentiates them from many other interdisciplinary projects described in the literature which mainly involved teaming electrical and electronics engineers with other disciplines. Examples include: mechatronics (with mechanical engineers, O'Connor *et al.* 2001); sensors (with physics); wearable computers (with computer science; Amon *et al.* 1995); and educational toys (with mechanical, IT and design; Ivins 1997).

The projects strongly reflect the School's research expertise as well as representing exemplars of complex and interdisciplinary undertakings: hydropower, potable water supply and micro-systems. These provide different combinations of disciplinary involvement (Table 1) as well as a wide range of physical scales ranging from nanometre-scale in micro-systems, up to hundreds of kilometres for the water supply project. The workload and assessment procedures for each exercise are broadly aligned and a reasonable degree of cross-marking is undertaken to ensure consistency in rewarding students for their efforts. Each project is led by a Visiting Industrial Professor together with an academic from the University.

	Discipline			
	Electrical	Mechanical	Civil	Chemical
Hydropower	Yes	Yes	Yes	No
Potable Water Supply	Yes	Yes	Yes	Yes
Microsystems	Yes	Yes	No	Yes

Table 1: Project participation matrix

While a full description of the implementation and experiences of all three projects is not practical here, two are described briefly here with the hydropower project described in detail in the next section. The potable water supply project tasks students with designing the infrastructure to meet Bangalore's increasing demand for drinking water, and includes the design and costing of diversions, pipelines, electrical supply, pumps and water treatment works. The project is led by a senior consultant at UK-based Mott Macdonald Ltd. The micro-systems project, led by a senior consultant at QinetiQ Ltd., requires students to design and simulate a sensor system for use in vehicle air-bags. The hydropower design project, led by the Chief Executive of the British Hydropower Association (D. A. Williams), is described in more detail below.

3 Hydropower Design

3.1 Project Objectives

The main aim of the project is to develop a well-balanced and full feasibility study for a small, approximately 1 MW, hydroelectric project located at Glen Kinglas in western Scotland. As well as producing a study which could be presented to a bank for funding, technical aspects had to be fully investigated and calculated before being presented in the final report.

Civil, mechanical and electrical engineers work in groups of six or seven students and investigate all aspects of the hydroelectric project. This covers hydrology to civil construction and pipelines, turbine and generator selection, control and auxiliary systems as well as the design of the connection with the local electricity system. These technical elements were underpinned by the requirement that their designs be economically viable to reinforce the idea that engineering activity is not independent of the wider market. The key feature of the hydropower design process is that to

achieve a viable project all major project components must be considered and optimised as an integrated whole.

3.2 Group Structure

Following a brief introduction, prospective honours students are asked to specify their preferences between the three projects. The aim of group selection is to ensure each group has an approximately equal number of mechanical, electrical and civil engineering students while meeting as many of the students' first preferences as possible. In the first year of operation (2004) this was a relatively straightforward exercise as preferences were almost equally split. In the following years there has been a marked preference for the hydropower project which perhaps reflects an increasingly environmentally aware student population or even the success of the previous years' project. Unfortunately, this has led to a degree of imbalance between the size of the classes and a reduced number of students receiving their first choice activity.

A major unknown at the outset was how collaboration within each group would work between the students from different disciplines. Most components of the scheme rely upon interaction with others, especially in the final analysis and selection of the optimum design. The necessity to give initial (topic and time planning) and mid-project oral presentations also initiated a good deal of combined planning and group working. Most groups had two students from each discipline which helped enormously in gaining peer feedback, confidence in the manner in which students operated and, in some cases, very innovative thinking.

An interesting observation was regarding team leadership. One group, from the outset, was 'taken over' by a dominant but diplomatic personality. As a result, the group was very well organised in its planning and presentation. Other groups did not have as clearly a defined leader and there was, at the other extreme, a rather amorphous loose-committee structure. Technically, all groups were competent but the group culture and interfacing skill in the one with the leader was much more effective. Based on this experience, students are now advised to carefully weigh the benefits of appointing a project manager.

3.3 Course Organisation

The exercise takes place within a strict ten week period from initial group selection and project definition to final presentation. The exercise represents a third of students' nominal work load during this period, the rest being traditional lecture courses followed by a final exam, and counts as a significant fraction of the final degree mark. The tight timeframe serves to motivate the students in managing their time effectively and provides a reasonably realistic simulation of the sort of pressures at work in industry.

A conscious decision was taken to give the students as much latitude as possible to organise their time, the scope of the work they had to carry out on their individual topics and how they operated within their groups. A website was set up to provide administration, instruction, guidance, reading lists, reference contacts and tutorial presentations.

One day a week when all students could, if necessary, work together was factored into each disciplines' timetable – a non-trivial task in itself. Lectures on particular topics were given on this day and the Visiting Professor was available for 'surgery' sessions for groups or individuals. This day was also used for the reporting sessions which were built into the project programme.

Giving the groups as much free reign as possible was an admirable concept and the results show that it was, to a large extent, successful. In the first year of running the course, the students were allowed virtually unlimited access to nominated staff at the University and to the Visiting Professor. The main drawback to this 'open' method of working was that demands on staff time were too great. This problem has been tackled by reviewing topics that have not been covered in the MEng syllabus' to date (e.g., grid connection) and developing more structured guidance. These have appeared in the form of short, targeted, lectures and notes and aim to 'short-circuit' common queries and difficulties and reduce staff loading. This is a common issue in such activities and must be carefully managed in order to avoid spoon-feeding yet minimise excessive staff demands. The approach mirrors the practice of supplementary instruction common in US Capstone courses (Todd *et al.* 1995).

Ensuring that students are, and are seen to be, properly supported by staff is a challenge in this activity. It is rare to find academics or industrialists who are competent or comfortable across three or more disciplines. A small number of nominated staff able to handle the deeper discipline-specific queries allows sufficient support for each discipline.

Assessment of the work was based around a series of milestones: an initial planning document, a short mid-project update and a thirty page final report supplemented by a presentation to a multi-disciplinary panel. Inclusion of the consulting engineer responsible for the successful feasibility study for the actual hydropower scheme on the project panel was invaluable in demonstrating that this was a 'real and relevant' project and benefited the staff by providing a deeper technical and economic insight.

3.4 Student Perception and Feedback

The amount of work required from the students was significant though, in some aspects, not too technically demanding. As might be expected the work rate grew exponentially as time passed! Group working on this scale and complexity was new to most students even without the added issue of interdisciplinarity. Bonding was well evident in almost all groups by the end of the ten weeks. Another new aspect for many was the preparation and giving of presentations: confidence appeared to grow towards the end of the project.

The nature of the project appeared to appeal to the majority of the students as it involves a renewable energy technology with tangible benefits for future energy production. This was reflected in the formal feedback from the students which indicated that they were very satisfied with the project and most described it as very interesting and relevant to their future career. The main negative comments included the short time-scale and the fact that they had to do this in parallel with other courses. The development of students' ability and comfort in handling material from outside their discipline was also tested using questionnaires at commencement and the end of the project. In the majority of cases students became more comfortable with other engineering disciplines and the use of economic information for decision-making. Of particular note was a large increase in the level of understanding between civil and mechanical engineers which perhaps reflects the degree of commonality between these disciplines.

3.5 Project Evolution and Outcomes

The project can be gauged as a success based on the continuing high quality of the final feasibility study reports, the oral presentations and the subsequent industrial impact. The students quickly adapted to working in a multi-disciplinary group environment and, in most cases, developed a selfless approach to the tasks. The technical conclusions of the project, although varied, addressed all the necessary issues and were accurate in observations and results. The only shortcoming remains in the area of a co-ordinated control scheme for the project which suffers as it is a cross-disciplinary topic: this will be given more importance in future.

From the second year of the course the Glen Kinglas scheme had become fully operational. This posed a problem as to how to prevent students being unduly influenced by the existing arrangements. While a series of alternative schemes were considered it was decided to stay with the original site, but adjust the exercise such that the groups were required to devise the economically optimal scheme in order to try and 'beat' the performance of the existing scheme. A major advantage of this was that it has put additional focus on using scheme economics as the basis for decision-making and justification. Further evolution of the project has seen the additional requirement to perform lifecycle energy and carbon dioxide audits of the scheme. The determination of carbon footprint will further enhance the students' skill set and will reinforce consideration of sustainability issues (Nair 1998).

In most cases, this is the first time students will be challenged directly on the regulatory, economic, social, and environmental context of their engineering work as required by UK-SPEC. Excellent examples of this is exposure to real-life legal, planning and technical standards such as Engineering Recommendation G59/1 (Electricity Association 1991) which defines the standards for connecting small generators to electricity networks as well as the environmental regulations relating to water abstraction and minimum river flows.

A further area is the exposure to uncertainty, whether this is through there not being a unique 'right' answer or the challenge of designing a component of a complex system without full knowledge of the final specification. The best organised, and therefore most successful, groups develop a matrix type of approach to the whole project. Some aspects were addressed in advance of all data being available from work which was

still progressing. This facilitates later inclusion of results allowing topics to be completed in a rational and accurate manner. The result is well balanced pieces of work which develop in a comparative rather than piecemeal manner. Alternative solutions are identified at an early stage and well-argued reasons evolve for choosing their optimum solution. Innovative approaches to some aspects were not constrained by a rigid work discipline being imposed on the project process.

Feedback from external bodies has been very positive. Accreditation visits from UK engineering institutions have specifically commended the School for their efforts in this and the other interdisciplinary design projects. The consulting engineer involved in assessing the course was impressed with the degree of understanding, detail and enthusiasm given in the oral reports and the accuracy of the final reports. He also thought that there was a definite link between the course and successful job prospects within the UK hydropower sector: to this end, several placements have been offered to students by UK hydro companies. Internal feedback from colleagues also indicates that those initially sceptical about the exercises have been impressed with the outcomes and standard of work.

4 Discussion

During its relatively short existence the hydropower design course has had several very successful outcomes:

1. It has given the students an appreciation of engineering disciplines other than their own,
2. The students experience working as a team, in which each member has different skills and expertise to contribute (most student group design projects involve students all studying the same course),
3. The project demonstrates how engineering design and economic viability are inextricably linked in projects of this type, and
4. The project provides an excellent opportunity to introduce students to non-technical topics (e.g., legal, sustainability, economic, regulatory) that are difficult to teach, but are required for the degree programme to meet accreditation requirements.

5. Experience to date suggests that this course is enhancing students' interest in the hydropower sector not only in terms of the technology but also in terms of it being a possible career

It is interesting to note that several students commented that they found this course every bit as demanding (and stressful) as conventional lecture courses examined in the normal way: it was certainly not seen as 'an easy option'. The key message from this project has been the need to ensure balance in:

1. The Task: It is essential that students from each engineering discipline feel that they have something to contribute from their own discipline. The hydropower project satisfied this requirement, as the individual tasks could be broken down almost equally into civil, mechanical and electrical components.
2. The Groups: It is very desirable that each group has an approximately equal number of students from each discipline, to avoid students from a less well represented discipline becoming marginalised. In the hydropower project, it was interesting to see that the students registered for the joint degree in Electrical and Mechanical Engineering were particularly highly valued by their groups.
3. The Support: It is unlikely that any single staff member (from industry or academia) will be able to provide the necessary support for all aspects of the task. It is therefore normally necessary to involve several staff from different backgrounds, to avoid students from one discipline feeling unsupported and left out.

5 Conclusions

This paper describes the experience of developing and operating an interdisciplinary hydropower design course to improve penultimate-year students' ability to operate across disciplines and improve their preparation for industry. Requiring students to provide a full feasibility study of a small hydropower and tackle issues from hydrology through to grid connection, the course has had several very successful outcomes. These include appreciation of other engineering disciplines; experience of multi-skilled teams; demonstration of the links between engineering design and economic viability; introduction to non-technical areas essential to the UK-SPEC; and

enhancing interest in the hydropower sector in technological and career terms. The key message from this project is the need to ensure balance across tasks, within groups and staff support across disciplines.

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8 Biographies

Gareth Harrison (Dr) is a Lecturer in Energy Systems in the School of Engineering and Electronics at the University of Edinburgh and holds Bachelors and PhD degrees

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Ewen Macpherson (Dr) is a Senior Lecturer and Head of Teaching in the School of Engineering and Electronics at the University of Edinburgh. From 1982 to 1984 he lectured on Power Electronics and Power Systems at the University of Technology in Lae, Papua New Guinea, where he was heavily involved in rural electrification programmes for remote communities, in particular utilising micro hydro and solar photovoltaic systems. His research interests are in power electronic interfaces for renewable energy systems and rural electrification in developing countries. He is a Fellow of the Institution of Engineering and Technology, a Member of the Institute of Electrical and Electronics Engineers and a Member of the Institute for Learning and Teaching.

David Williams is Chief Executive of the British Hydropower Association, the trade body promoting the UK hydropower sector and is a Visiting Professor at the University of Edinburgh leading the hydropower design course. He was formerly an export promoter at the Department for Trade and Industry and Manager of the Hydro Division of Gilbert Gilkes and Gordon Ltd.